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CONCRETIONS IN OTWAY GROUP SEDIMENTS, SOUTH-EAST AUSTRALIA

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Abstract: Concretions are characteristic of the Otway strata and are best seen along the coast. They are cemented by carbonates, viz. calcite (by far the most common), siderite and ankerite. The concretions are stratified; they are not derived but were formed in the sediments before compaction and while the strata were still horizontal. They were jointed and faulted by the tectonic movements that updomed these rocks. Post-tectonic calcite, pyrite, aragonite and barite (in order of abundance) occupy joints and fault planes.

INTRODUCTION

'No one can do effective research in any field unless he enthusiastically enjoys doing it.'
(Professor Sir MacFarlane Burnet)

The highly feldspathic Lower Cretaceous sandstones (arkose or greywacke according to the definition used) of the Otway Group (especially the Otway Ranges) are characterized by concretions. These accretionary growths all have carbonate cements, and so the term *concretion* (Latin *con* + *creta* = cemented with carbonate) is apt. They are particularly in evidence on the extensive shore platforms of the Otway coast, where they stand out because of differential erosion. All occur in arkose, a function of arkose porosity, and none in siltstone. NHMcN studied their occurrence from Eastern View to Point Flinders west of Cape Otway. EDG investigated their geology (including x-rays of rock slabs) and chronology, and ERS the petrography and mineralogy.

MORPHOLOGY

The commonest shape in calcite, siderite and siderite-ankerite concentrations is a spheroid (Pls. 9-10, 11, fig. 2). This suggests radial growth, which in some instances can be proved by concentric structures (Pl. 10, figs. 3-4); also some concretions break away in shells (Gill & McNeill 1973, Pl. 2). Occasionally the sideritic types form a string. Calcite spheroids are not usually so jointed, but more elongate ones may so occur, being known locally as 'sausages'. Calcite spheroids occur in a great range of sizes, but the majority have a diameter of 0.1-0.3 m. The siderite and siderite-ankerite types are usually in the lower part of this range.

Other concretions are platey. The largest concretionary masses cover a range of shapes from platey to pillar-shaped. The Artillery Rocks get their name from the presence of pillar-shaped (cannon) and spheroidal (shot) concretions. Platey forms also occur there. Some of the pillar type flatten to become 'pillows'. The longest measured was about 6 m. The large concretions of whatever shape have joints through them, even when no or few joints occur in the matrix. This is interpreted as a function of a rigid material in a less rigid matrix. Occasionally a close reticulate jointing occurs, wherein a secondary mineral may be deposited to give a septarian appearance. In others, the joints are more or less normal to one another, and when excavated by erosion, the concretion looks like a tray of large loaves. Such can be seen at the north-east end of the shore platform north of Stony Creek, Lorne, and also west of Eagles Nest in South Gippsland on a shore platform. Sometimes the points are infilled with iron oxide. When the joints cross obliquely the effect is that of Tudor house panelling.

The Artillery Rocks site is a virtual museum of calcite concretions, which are present in large numbers and great variety (Pl. 9, fig. 1). Quite remarkable shapes occur. It has been recommended that the place be preserved as a monument.

STRATIGRAPHY

The Otway coast concretions are stratified, i.e. they are limited to particular beds. Therefore one of the

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factors controlling the number appearing on a given platform, and so the degree of resistance to erosion, is the dip of those beds. At North Lorne on the north-east side of Stony Creek is an extensive flat supratidal platform (locally called Jump Rock) 58 m wide and 213 m long. The strata are unoxidized, as the sea has cut deeply into a large spur. The dip is 10° seaward. Calcite concretions there range from 1 cm to 1 m in diameter, and can best be seen at the north-east end of the platform. Three lines of concretions project from its surface: one of the platey type, one of average size spheroids, and the third of small spheroids. This range at such close intervals indicates a range of geochemical conditions in beds lithologically the same. The lines follow the strike, and at the end of the platform where it drops 2.5 m to a siltstone platform below, they can be seen to follow the dip. The platey type is oriented to the containing stratum.

Nodules of pyrite occur on this and many other platforms, but are not stratified. Nevertheless these nodules are limited to particular areas and so must be a function of a suitable geochemical environment not present everywhere. The mineral is pyrite, not marcasite, so the conditions were neutral or alkaline, in spite of the common occurrence of plant material. In their distribution across the beds and their independence of the presence of plants (suggesting that decomposition was finished), the pyrite occurrences seem to be related to post-tectonic conditions and not to the time when the beds in which the concretions were formed were still horizontal. Other evidence in this connection will be discussed later in the paper. The pyrite fills joints as plates of plain or fibrous mineral, while many nodules have been found (e.g. north-east of Big Hill Creek) which have numerous cubic system faces.

Calcite is common in two roles. The first is as concretions limited to particular strata, and the second is an infill mineral in joints and fault planes. Edwards and Baker (1943) record 'veins up to several feet thick'. They analysed calcite concretions and found they contained 25-49.3% of that mineral, while their matrices possessed only a few per cent. The ultimate source of the calcium is no doubt weathered feldspar from the Victorian/Tasmanian granodiorites, but the more immediate source may be the weathering of older shales or the greywackes (arkoses) themselves.

Fresh rock breaks across the grains due to the presence of cement, the commonest of which is calcite. The concretions apparently grew from centres of crystallization till the free carbonate was used up. However, there are places with plenty of carbonate but not concretions, which could indicate a second generation of carbonate. This is discussed later. Other rock cements are chlorite (Edwards & Baker 1943) and laumontite (determined by D. S. Coombs). Laumontite rosettes are not uncommon in rocks of this age in South Gippsland (Gill 1957). Some were found in fossil wood in the shore platform below Cinema Point by NHMcN — the first record from the Otways.

On the Mt. Defiance coast between the Cumberland and Jamieson Rivers, siderite-ankerite concretions occur in great numbers. The matrix is unusual in colour in that it is grey instead of greenish grey, although an occasional bed of the latter colour may be found. This block is bounded by strong faults, and the dips are exceptionally high for Lower Cretaceous beds in this region, reaching 90° at Mt. Defiance. This particular type of concretion is found only on this part of the coast, and is present in such numbers as to assist definition of the lithology (Pl. 9, fig. 3). Thus the concretions could be used along with the grey colour to define this block as a new formation.

As the calcite concretions (and indeed all the concretions as here defined) are limited to particular strata, they can be used for measuring the throw of faults. Thus the fault on the right bank of St. George River at its mouth is covered in the roadcut by a cone of talus and colluvium. However, on the seaward side is a concretion bed dipping at 20° and on the landward side the same bed can be recognized dipping at 28° from which the throw of the fault can be measured at about 7.3 m. Judging by the slickensides, and the crush zones in the shore platform at the mouth of the river, a good deal of movement has occurred. The fault has a strike of 65° magnetic.

The first concretion studied was a calcitic oblate spheroid from the intertidal shore platform on the south-west side of Stony Creek at Lorne (Pl. 10, figs. 1-2). This specimen belongs to a group that is unusual since instead of a hard resistant surface it has a soft oxidation zone, thin underneath, thick (17 mm) on the sides, but thin on top due to erosion. Its external colour is dark reddish brown (Munsell 5YR 2/2). The concretion came away from its matrix neatly, showing that a distinct interface existed between concretion and surrounding rock. The white zone in Pl. 10, fig. 1 is salt (NaCl), and has a maximum thickness of 4 mm. A slide of the rock was x-rayed in the Faxitron machine at the National Museum of Victoria (cf. Bridgman 1973), and part is reproduced in Pl. 10, fig. 2. This reveals very fine horizontal layers with little bifurcation or lensing. Heavy minerals are common, causing the dark lines in the x-ray. From an enlargement it was possible to count 100 clear layers in 103 mm. There are probably a total of 175 layers in the whole section. Lenses of heavy minerals (including magnetite) are found occasionally in the Otway rocks, but the common occurrence of black sands on the existing beaches shows that it is a common component of the sediments. Heavy minerals caused the unusual oxidation in this concretion. South-west of Boggaley Creek there is an area of strongly oxidized platform unusual for this coast. Heavy minerals occurred as bun-shaped concretions and also in the bedrock, thus causing the high degree of oxidation.

On a cliff re-entrant at the south-west end of the supratidal platform that extends from Cinema Point towards Lorne, fine bedding is picked out by differences in carbon content, and these are seen to pass through the concretions without interruption (Pl. 11, fig. 1). This same stratigraphic relationship can be demonstrated for all the types of concretions, e.g. a polished medial section through a siderite-ankerite concretion from the Mt. Defiance shore platform shows a thin layer of breccia with numerous shale chips which passes through both the concretion and the adhering matrix. This was confirmed by x-ray of the concretion using a thin slab from the middle of the specimen.

Thus the continuity from matrix through concretion to matrix again of specific layers and of sedimentary structures such as current bedding proves that the concretions are younger than the sediments, i.e. they are not derived. The question is how much later were the concretions formed? This will be discussed in the section on chronology.

WEATHERING

Calcite concretions are the dominant type, and where exposed on the shoreline have suffered no obvious weathering except for occasional pitting. They are denser than the matrix, i.e. their porosity is lower. Because of the susceptibility of black sands to weathering, concretions formed in sediments rich in this component have a weathered cortex (Pl. 10, fig. 1). This cortex is porous, and hence the salt layer at the interface of the cortex and the unweathered part of the concretion. Salt is often credited with causing decrepitation of the rock face, but here anyway it is concentrated without any visible effect. Both the siderite and the siderite-ankerite concretions have a cortex of weathered rock.

As siderite weathers readily, it may be possible to utilize it for measuring the weathering rate. At Mt. Defiance there are plenty of concretions exposed in the cuttings in the Ocean Road, but none are oxidised except for some soft porous ones. The road was opened in 1932 and the work commenced about 1930, so the concretions have been exposed for about 45 years. Taking into account the retrogradation rate of the arkose of 0.9 cm/yr (Gill 1973), 100 yr should be significant. At the north-east end of the Mt. Defiance platform in March 1973, an undercut mass of arkose was seen to have broken into three units, two of which moved north-east along the strike parallel to the shore so that the three were separated. The largest gap was 1.75 m between the north-east (4.9 m long) and middle (5 m long) blocks. The rock faces in this gap are about 2.7 m wide, 1.4 m high on the landward margin (which is up the vertical bedding plane) and 0.2 m on the seaward margin (less because of undercut). When first viewed these faces were fresh and without epifauna, and so the fractures were new. It is interesting to note that the breaks did not sever the concretions, but one face or other contained the whole concretion, while the opposite face contained the mold. This means that the secondary mineralization during concretion formation strengthened the rock, and that there is a definite concretion/matrix interface. By November 1974 two species of limpets, probably three of *Melarapha,* and a green seaweed had colonized the rock faces. Check in 1975 showed more epifauna but no change in oxidation. So an oxidation cortex of 0.5-1 cm in specimens examined must require considerable time. A closer examination of concretions in the newer and older parts of the platform, and a search for them below sea level may assist quantification.

It is significant that honeycomb weathering (tafoni) does not develop on concretions, but may be excellently developed in the matrix right up to the concretion surface (Pl. 9, fig. 1). Concretions on pedestals at Artillery Rocks have their pedestals appreciably weakened by deep honeycomb in the supratidal zone. However as already noted, pittings, usually well separated, are found on the concretions.

EROSION

Concretions project from the rock surface in all zones of the shore. As they are denser and heavier, they resist erosion more successfully than does their matrix, and so stand out from platform and cliff as a function of differential erosion. In the higher energy zones the concretions are dislodged earlier than in the lower energy areas of shore and cliff. When dislodged before the base is eroded away, they leave craters (Gill 1967, Pl. 33, fig. 2; Gill & McNeill 1973, Pl. 1).

An assessment of the rate of concretion removal can be made by studying old dated photographs. For example, Jutson (1954, Pl. 7) figured a row of calcite concretions on the shore platform south-west of Point Grey, Lorne (about 0.5 km north-east of the St. George River mouth). The concretions are grey (10 YR 5/1), the matrix greenish grey (5 GY 6/1), and the joints dark reddish grey (5 YR 4/2) — all colours dry. The seven concretions are in a single bedding plane normal to the shore, and they are here (below) numbered from the seaward end. Since 1954 two concretions have been removed and could not be found, the two in the vicinity being of the wrong size; also the top half of concretion one had been removed. All are in the *Melarapha* zone, i.e. supratidal.

Jutson's concretions are actually the first seven of 27 running along the strike from an incipient channel at the seaward end to a steep ramp at the base of the cliff:

1. Diameter 0.47 m but 10-20 cm eroded away on the south-west side, and the top removed; 10.7 cm above the platform on the landward side and 20.5 cm on the seaward.
2. Diameter 40.5 cm, height 20.2. Pitted on top. Largest concretions at this end of the row. For concretions 2-7 see Pl. 11, fig. 2.
3. Double concretions (a) diameter 39 cm x 10.9 high, joined by neck 14 cm wide to (b) 26 x 5 cm. (a) pitted on top.
4. Removed, but ferruginous concave base 34 cm wide.
5. 33 x 8 cm.
6. Removed, but base 27 x 6 cm.
7. 25 x 4 cm. Not fully exposed. From this point to the ramp, the platform surface is covered with sand, shells and pebbles.

8-27. Beyond Jutson's photograph. Of this series 14-15, 17, 20-21 and 26 have been removed, leaving craters.

These observations and photographs, taken March 1973, can be used for a further check in years to come.

Light is thrown on the process of shore platform erosion by pedestal and mushroom rocks. An example is found on the siltstone platform on the small headland south-west of Point Sturt (north-east side). The caprock is arkose, the pedestal siltstone. The site is intertidal as shown by *Hormosira* seaweed and *Galeolaria* calcareous worm tubes. As is usual, more vertical than lateral wear has taken place. The passing sea-water armed with sand, shells and pebbles is the same cutting compound that erodes the platform. The caprock must in some way afford protection. The siltstone surface is rough, so the rock must be plucked by the sea and/or fretted by wet/dry decrepitation. By contrast, a pair of arkose pedestals in the supratidal zone at Artillery Rocks have relatively smooth stems, although there is differential erosion. In the supratidal zone there are many pedestal rocks (concretions) with their stems covered with honeycomb (Pl. 9, fig. 1). One on the north-east side of the deep gulch stands more than 0.5 m above the platform. It is remarkable that the downwear has been many times greater than the sidewear. Where the paired pedestals stand in the lower part of the supratidal zone, storm waters spurt between them with considerable force, yet the downwear still far exceeds the sidewear. In the higher part of the supratidal zone honeycomb weathering covers the stems and the higher parts of the platform, but the rest is worn smooth by the swash surges.

On the north-east side of the gulch the erosion is complex, but on the south-east side where it is more homogeneous, there are two distinct levels of platform. The lower is cut in strata without concretions, while the higher one is essentially a dip slope due to the resistance offered to the sea by the many concretions. The strike is parallel to the shore and, as elsewhere, the concretions are stratified, as can be seen neatly in the gulch walls. When the platey concretions (Pl. 11, fig. 3) are pulled away from the platform by storm waves, they cause much wear before they are disposed of down a channel or into some other negative part of the coastal morphology.

MINERALOGY

Calcite concretions: Those figured (Pl. 12, figs. 1-2) are from the intertidal arkose shore platform south-west of Little Stony Creek, Lorne. They are greywacke-type arenites of quartz grains, finely granular quartz particles, feldspar grains (both plagioclase and microcline, fresh and weathered), coarse muscovite flakes and chlorite particles, and abundant fragments of shale. The particles tend to be well separated, and cemented by finely crystalline calcite. Apart from a slight variation in grain size, a 6 cm section across the bedding of the concretion does not show the banding recorded by the x-ray. This is because the x-ray slab was about 2 mm thick whereas the microscope slide was 0.1-0.01 mm.

Siderite concretions: Those figured (Pl. 12, figs. 3-4) are from the shore platform north-east of Big Hill Creek, north-east of Lorne. The sectioned one is a grey concretion with a red-brown outer zone 10-15 mm thick. This again is a typical greywacke composed of abundant small shale particles, quartz and feldspar, but cemented with siderite. It is poorly crystalline and so does not give an x-ray diffraction pattern, but the colour suggests haematite rather than goethite. These concretions are quite different in appearance from those with siderite-ankerite cement in the Mt. Defiance area (cf. Pl. 9, fig. 2 and Pl. 9, fig. 3). The siderite concretions are comparatively rare.

Siderite-ankerite concretions: These occur in great numbers in the shore platform below Mt. Defiance between the Cumberland and Jamieson Rivers (Pl. 9, fig. 3). The siderite forms a zone round the detrital grains, while the ankerite fills the interstitial spaces with a clear, more coarsely crystalline carbonate. Some specimens contain a fine seam of breccia with particles of shale up to 10 mm diameter. Cementation probably began by deposition of carbonate at discrete points, from which growth has continued from carbonate brought in by percolating waters. The Fe^{2+} of the siderite could have been derived from alteration of pyrite, or by reduction of iron compounds by carbonaceous material or anaerobic bacteria. The presence of two carbonates, deposited sequentially, indicates changes in groundwater conditions.

CHRONOLOGY

In that the carbonate concretions are all strictly related to the bedding, they must have formed while the beds were horizontal. Because the mineral grains on the whole are well separated, and the cement or cements fill the spaces, compaction was not well advanced when they formed. No seams of siderite or ankerite fill joints. Later carbonate and sulphate which did fill joints and occupy fault planes are calcite, aragonite and barite (found at Cross Springs by NHMcN). Moreover, the concretions are involved in the faulting and jointing. For example, there is a long open cave (unnamed) at about the level of the top of the first high waterfall on the Sheoak River about 0.5 km from the sea. Numerous jointed concretions are in the wall of the cave and some have been displaced on faults but the greatest throw was only 3 cm. Of 35 concretions in the cave, 17 had joints while 18 showed movement, and so technically are faults. In all instances, the breaks were filled with crystalline calcite. Further upstream is a second cave called Swallow Cave. A short distance upstream from it are joints filled with calcite 1 cm or more wide, with crystals of calcite down each side of the joint, and crystals of pyrite in the middle.

The updoming of the Otway rocks created tension which probably accounts for the open joints often filled with calcite. The uplift would bring about active weathering of these highly feldspathic strata and so yield much carbonate in addition to the sources mentioned earlier, e.g. bedrock shale. There appear to be two generations of carbonate, that which formed the penecontemporaneous concretions, and that which followed uplift and filled the opened joints. Pyrite nodules are found, and pyrite filling joints. This mineral, the aragonite, and the barite, appear to belong to this second generation of minerals. The pyrite is not related to the bedding so much as to the jointing. The concretions were formed after the sediments were emplaced, while they were still horizontal, before compaction had proceeded far, and before the tectonic movements began. They are probably Cretaceous in age. The folding, faulting and jointing were caused by tectonic movements, probably during the breaking away of Australia from Antarctica (Gill 1975). If so, the pyrite, barite and second generation calcite are Tertiary in age. The aragonite, being comparatively unstable, suggests a younger date for the joint fillings.

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EXPLANATION OF PLATES 9-12

PLATE 9

FIG. 1—Grey calcitic concretions in supratidal shore platform at Artillery Rocks, south-west of Lorne. The concretions follow a seaward dip slope. The coast is of high energy and swash circulates among the concretions, so producing a smooth surface. Above this, tafoni occupies the surface of arkose pedestals, but ceases at the concretion, on which some pitting may be found.

FIG. 2—Reddish-brown sideritic concretions on shore platform north-east of Big Hill Creek, north-east of Lorne.

FIG. 3—Reddish siderite-ankerite concretions in grey arkose (greywacke) on the supratidal shore platform and cliff at Mt. Defiance, south-west of Lorne.

PLATE 10

FIG. 1—Polished section of calcitic concretion from arkose with fine layers of heavy minerals (Fig. 2), supratidal shore platform, south-west of Little Stony Creek, North Lorne. The outer crust is brown (oxidized) with a layer of salt (white) at the base. The rest of the section is grey.

FIG. 2—Same concretion. Part of x-ray of median slab to show heavy mineral layers, which continue through to the matrix.

FIG. 3—X-ray of a calcite concretion showing concentric structures.

FIG. 4—Brown weathered (oxidized) concretion in arkose (greywacke) with heavy minerals, producing ?haematite. Note concentric structures.

PLATE 11

FIG. 1—Calcitic concretions in cliff above supratidal platform south-west of Grassy Creek (Cinema Point). Fine carbonaceous bands in the matrix continue through the concretions, showing that the concretions are secondary.

FIG. 2—Present state of Jutson's 1954 concretions on shore platform south-west of Point Grey. No. 1 is out of sight (top half removed). Nos. 2-3, 5 and 7 are still in place, but erosion has removed 4 and 6.

FIG. 3—Horizontally oriented concretion (calcitic) at Artillery Rocks, south-west of Lorne, stratified in arkose.

PLATE 12

The short graphic scale at foot of Fig. 6 applies to Figs. 1 and 3, while the long scale applies to the remainder of the figures.

FIGS. 1 and 2—A calcitic concretion from shore platform south-west of Little Stony Creek, North Lorne; shows typical greywacke texture. Dark shale particles, clear quartz and unaltered feldspar, with grains separated by calcite cement.

FIGS. 3 and 4—Siderite concretion from shore platform north-east of Big Hill Creek, north-east of Lorne. Particles cemented by siderite on right. On left, siderite oxidised to ferric oxide.

FIGS. 5 and 6—A siderite-ankerite concretion from the shore platform at Mount Defiance, south-west of Lorne.


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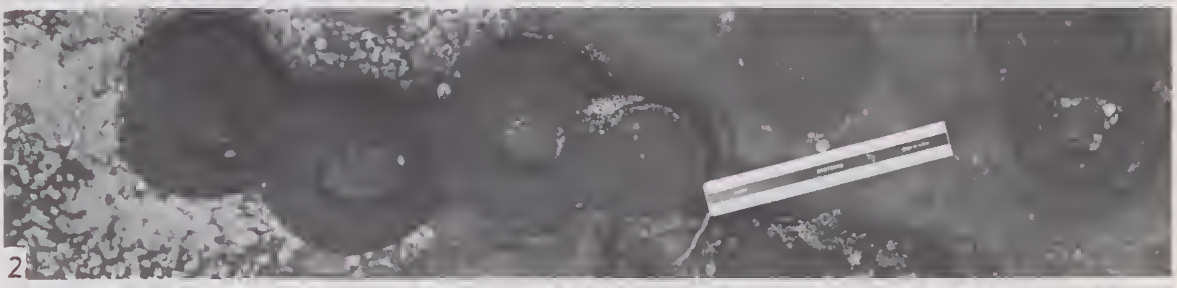
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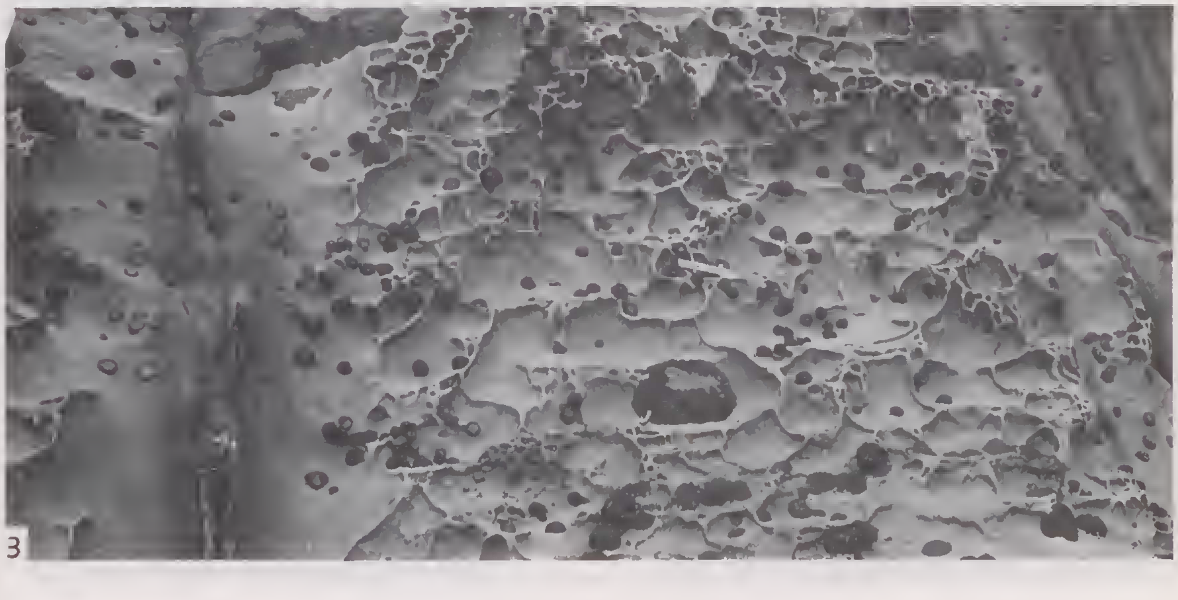
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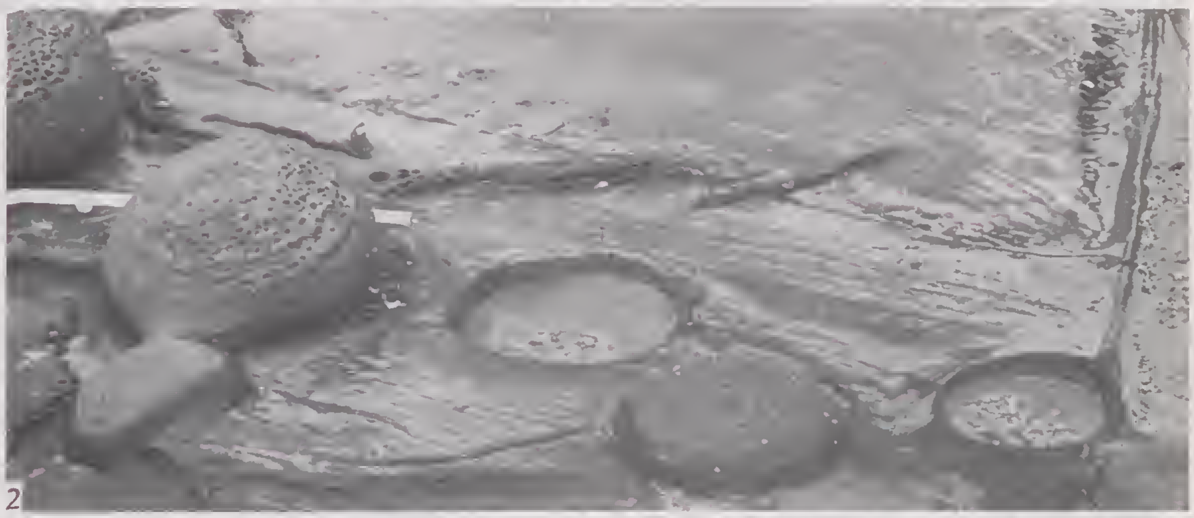
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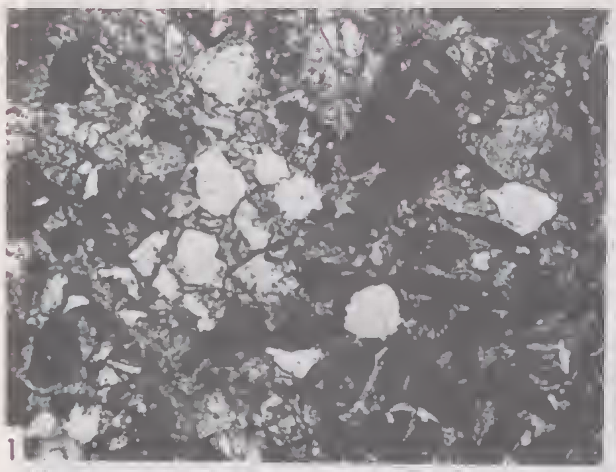

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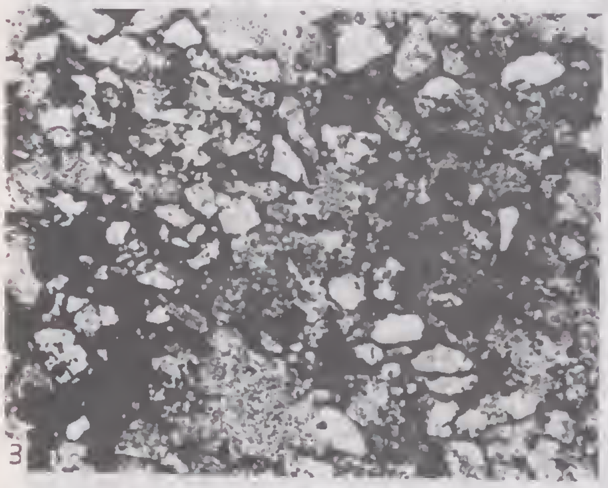

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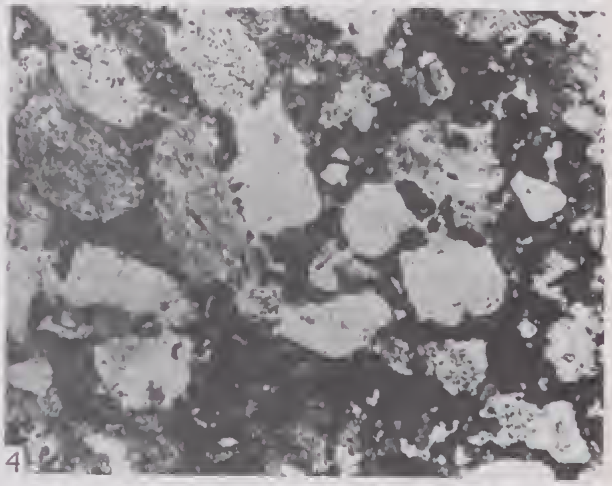

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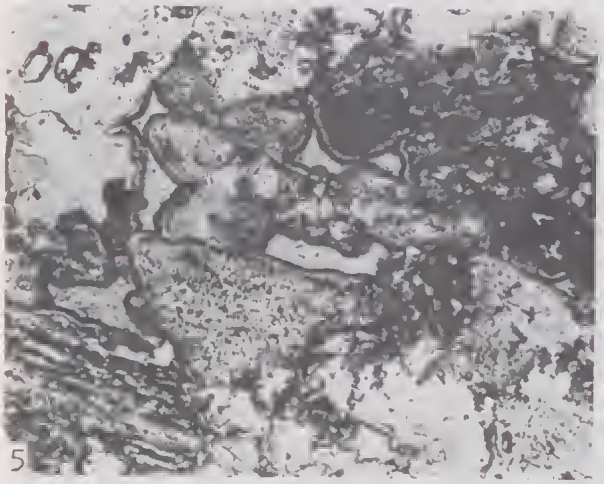

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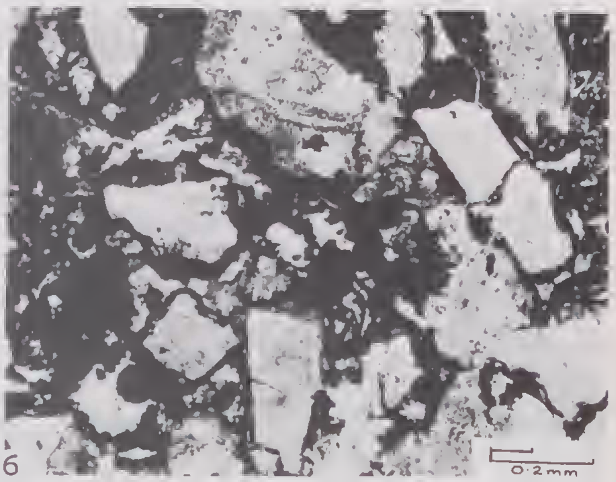

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